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PROGRESS REPORT ON IN SITU HEATER EXPERIMENT

by

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SUMMARY

The in situ heater experiment has suffered a delay of almost one year due to the shut down of Creighton Mine, the location of the experimental site. The additional time was used to modify the heater, add the U.S.B.M. deformation meter to the list of experimental transducers and to perform extensive calibrations of the transducers used in the experiment. The workers at Creighton Mine returned to work on June 5, 1979 and the project is now expected to be completed by the end of 1979.

1. Introduction

The purpose of this report is to review the development of the in situ heater experiment task for the period since the last progress report (1) in February 1978. During this period the instrumentation has been brought together, several pieces of specialized equipment were constructed and where necessary equipment calibrated or interfaced. As well the long delay in the project has permitted improvements to be made in equipment and transducer calibration procedures. The delay resulted from the shut-down of Creighton mine**, first for an extended six week vacation break in July - August 1978 because of the company's large metal stockpile and then again in September 1978 because of the workers strike against Inco Metals Ltd.

Several stages of the project were complete at the time of the last report:

- development and evaluation of the test site
- numerical modeling of the heater test
- design of the experimental layout

As well the purchasing and development of the necessary equipment was already in progress. Instrumentation was scheduled to begin in September 1978.

The strike has delayed the project by preventing access to the mine. Before instrumentation can begin the mine must reopen and those contracts for site preparation, originally tendered for the summer of 1978 will need to be renewed. Some of these were held with Inco Metals Ltd. for the pro-

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** Creighton mine is the location of the experimental site, just west of the city of Sudbury, Ontario.

(1) Progress report on the In Situ Heater Experiment, G. Larocque et al, Mining Research Laboratories, Feb. 1978, Report No. MRP/MRL 78-37(TR)

vision of services to the site; construction of a gate; and the drilling of the 31 cm diameter heater hole. Other contracts with outside firms will need to be renewed for diamond drilling the 3.8 cm instrument holes; removal of a 2 m long steel casing from the site floor; and the grouting instrument holes after thermocouple installation.

When the extent of the delay was first realized, a decision was made to use the time for improving our state of preparation. The laboratory studies were expanded to include individual calibration of the transducers; development of specialized equipment to assist in instrumentation and in the site survey; and a major redesign and reconstruction of the heater. The heater design was changed to allow for easier and surer installation and to allow for the measurement of surface temperatures on the rock wall next to the heater.

The areas where effort has been applied over the last year are outlined in Table I. These include the originally planned activities as well as the expanded program. A full break-down of tasks appears in Appendix A, along with the names of the individuals, who under the direction of Mr. G. Larocque*, were responsible for the completion of each task.

Table 1. Areas of Project Advancement

equipment development
interface construction
transducer calibration
computer programming
instrument testing
equipment logging and crating

Most of the work outlined in Table I is complete except for parts of the data conversion programs involving the newly obtained calibration curves, construction of some of the simple devices required for the site survey and the crating of equipment which was used in the calibrations. This report describes the work done in the preceeding year under the headings in Table I. Also a section entitled "Future Plans" outlines the sequence of

* Manager, Rock Mechanics Laboratory, MRL, CANMET, EMR.

events anticipated, leading up to and including the running of the experiment. More detailed reports in these areas are now being prepared and will be released at a later date.

2. Equipment Development

Much of the equipment for the experiment has been purchased as "off the shelf items". Certain components however, were of such a specialized nature that they had to be constructed in the laboratory. These were:

- the in situ heater itself
- certain survey accessories
- a surface temperature measuring system for the heater hole
- a down hole carriage for the heater hole survey and instrumentation
- mounting blocks for the shielded thermocouples

The in situ heater consists of four cylindrical black iron shells 30 cm in diameter and 164 cm in length. Fig. 1 is the end view of one segment showing the twelve resistance strip heaters around the inside, the turnbuckles used to pull the heater into shape and in front the three steel bars used to attach the adjacent segment. Two segments partially assembled are shown in Fig. 2. Fig. 3 shows the bottom segment with the water pump extending below it as it will in the field. Each segment has an input resistance of 10.6 ohms and is rated for a maximum of 480 volts or 21 Kw. In this experiment the heater will be powered with 95 Vrms for a power dissipation of 850 watts/segment. The heater was designed to have 0.5 to 1.5 cm clearance when lowered into the heater hole. Centering will be achieved by using three spring steel spacers around the cylinder at each of five levels down the length of the heater as shown in Fig. 4. Also shown in this drawing is the pump assembly, the water pipe to the surface, the one-ton hoist suspending the heater and the 3.8 cm conduit used to protect the wiring. Fibreglass insulation will be used to fill each segment and to fill the region above the heater in order to minimize heat transfer upwards by air convection.

The clearance between the heater and the borehole is provided to allow a trouble free installation as well as to prevent the uneven heating of the rock. This would occur if direct contact was made between the heater and the rock wall.

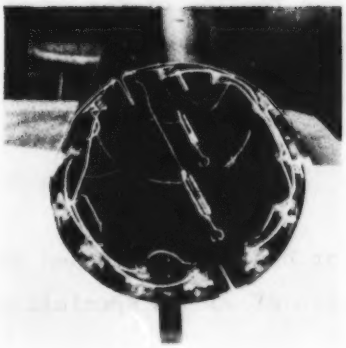


Fig. 1. End view of one segment of the in situ heater.

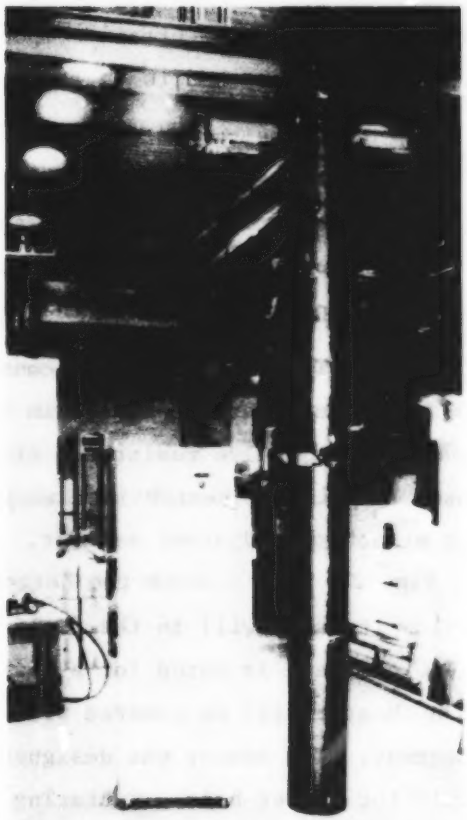


Fig. 2. Two heater segments assembled (right), power supply and controller (left)

Fig. 3. Lowest heater segment with pump assembly attached.

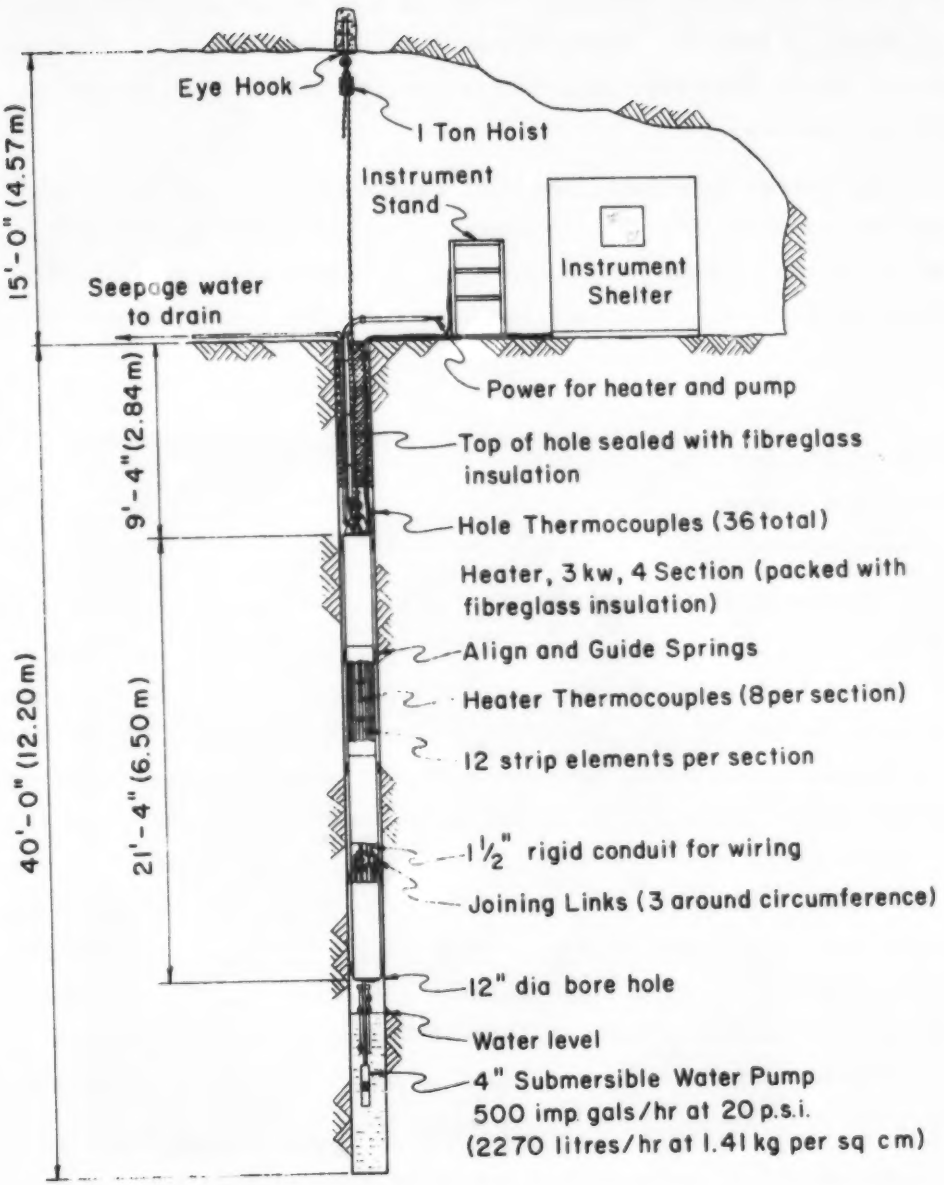

Eye Hook
1 Ton Hoist
Instrument Stand
Instrument Shelter
Seepage water to drain
15'-0" (4.57m)
9'-4" (2.84m)
40'-0" (12.20m)
21'-4" (6.50m)
Power for heater and pump
Top of hole sealed with fibreglass insulation
Hole Thermocouples (36 total)
Heater, 3 kw, 4 Section (packed with fibreglass insulation)
Align and Guide Springs
Heater Thermocouples (8 per section)
12 strip elements per section
1½" rigid conduit for wiring
Joining Links (3 around circumference)
12" dia bore hole
Water level
4" Submersible Water Pump
500 imp gals/hr at 20 p.s.i.
(2270 litres/hr at 1.41 kg per sq cm)

Fig. 4. Schematic of the in situ test site.

The clearance also provides room to attach thermocouples to the rock wall. A thermocouple is silver soldered to a 4.05 cm diameter disc of 0.2 cm thick mild steel (see Fig. 5). The disc is then attached to the rock wall with epoxy using the hydraulic mounting tool equipped with magnetic heads as shown in Fig. 6. Thirty six such thermocouples are to be mounted in the heater hole in this way, in order to monitor the boundary temperature between the rock and the heater.

The heater hole instrument carriage used to carry the hydraulic mounting tool shown in Fig. 6 is designed to travel along in a fixed orientation to the axis of a borehole which is roughly 31 cm in diameter. Figs. 7 (a) to 7 (d) show the carriage with its various attachments which include:

- hydraulic mounting tool
- survey inclinometer
- borehole camera
- borehole washer

The survey inclinometer is a commercially available instrument and the borehole camera, although designed and built in this laboratory, has been used in other applications. The hydraulic mounting tool and the borehole washer were designed and constructed specifically for this project. The mounting tool is a hydraulic cylinder which has opposing heads which may be extended or retracted depending on the direction in which the hydraulic fluid is pumped. The heads contain electromagnets which hold the steel plate thermocouples in place. The power dissipated by the magnets also serves to heat the disc and accelerate the curing of the epoxy. To clean the hole before thermocouple installation the borehole washer is used. In principle it is very similar to a lawn sprinkler in that it sprays water under medium pressure from opposite ends of a copper pipe which can rotate rapidly as a reaction to the force of the spray.

The shielded thermocouples are to be grouted into the 3.8 cm boreholes located around the heater hole. The experiment requires that the position of each thermocouple be known accurately. To achieve this the thermocouples will be attached to a rigid strip of fibreglass board (Fig. 8). The board is then lowered into the hole and positioned accurately before the entire assembly is fixed into position by grouting. In this way the thermo-

Fig. 5. Metal disc with thermoucouple attached.

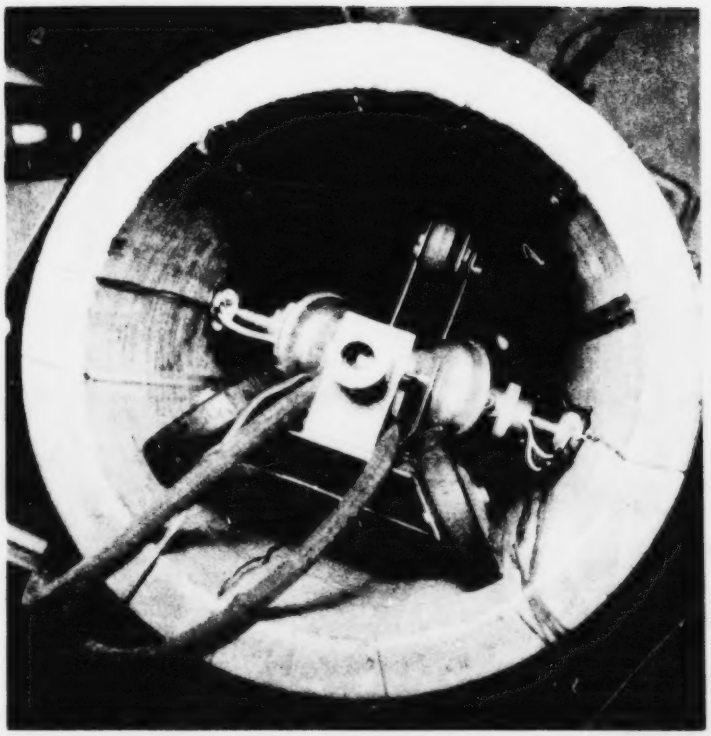


Fig. 6. Hydraulic Mounting tool in operation.

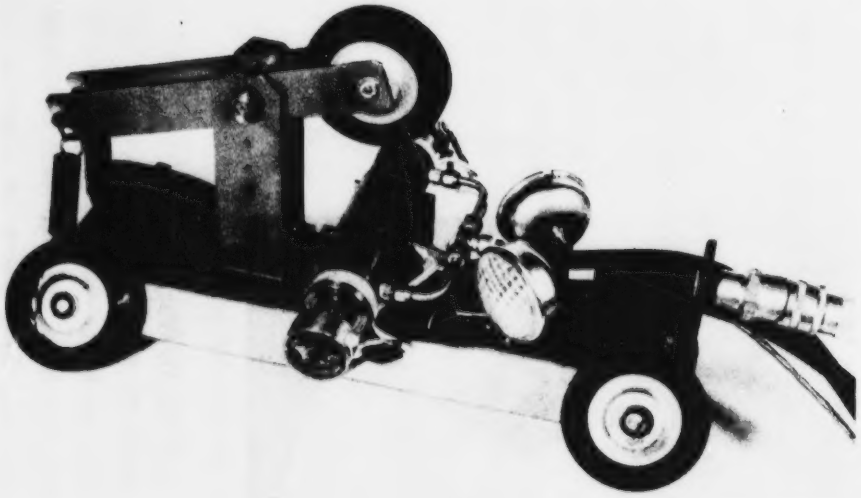


Fig. 7(a). Down hole carriage with hydraulic mounting tool

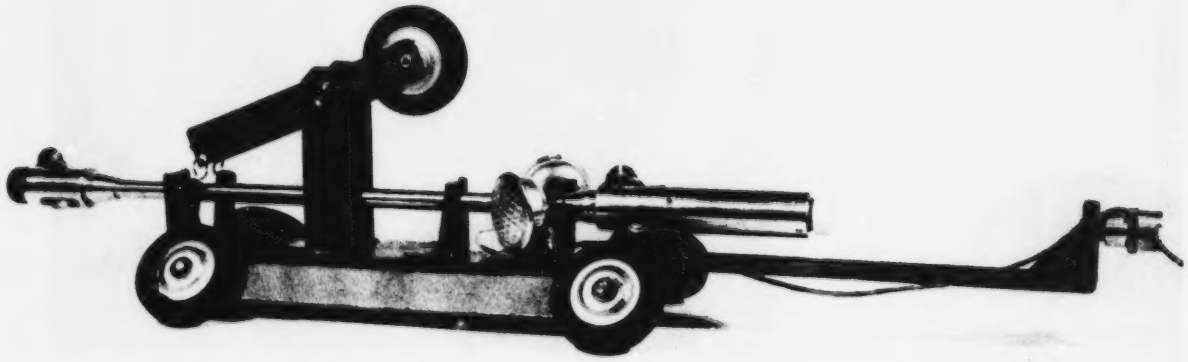


Fig. 7(b). With inclinometer

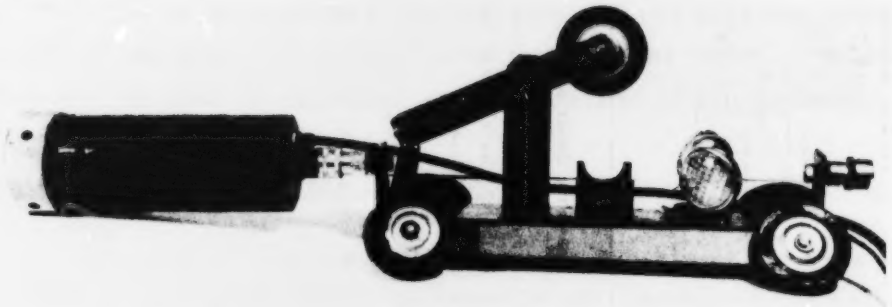


Fig. 7(c). With borehole camera

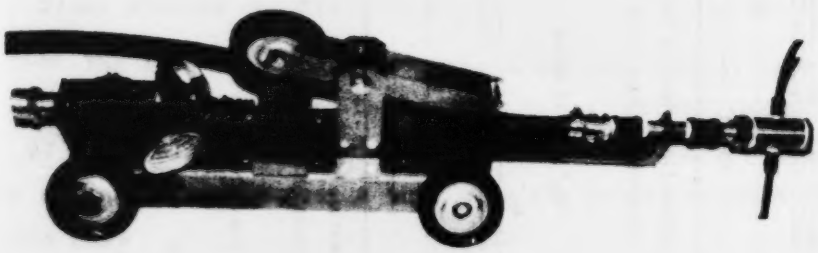
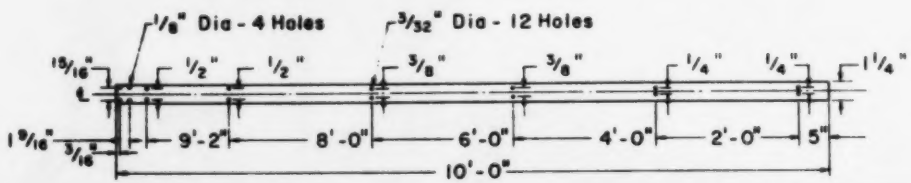


Fig. 7(d). With borehole washer

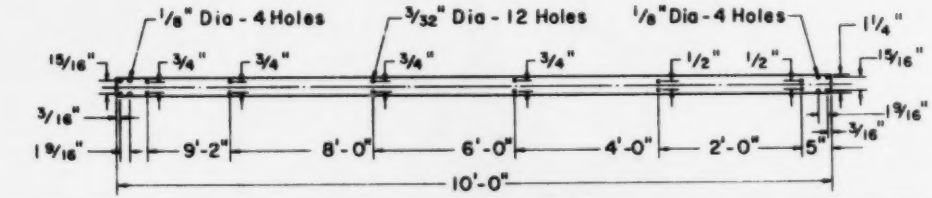
Part 1, Thermocouple Armature (Bottom Section)

Material: 3/16" Thick High Temperature Fiberglass



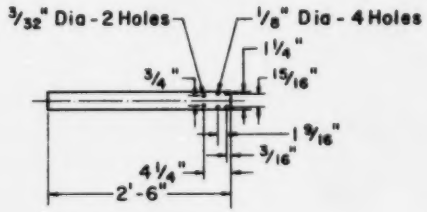
Part 2, Thermocouple Armature (Intermediate Section)

Material: 3/16" Thick High Temperature Fiberglass



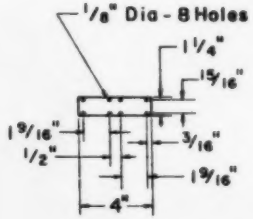
Part 3, Thermocouple Armature (Top Section)

Material: 3/16" Thick High Temperature Fiberglass



Part 4, Connecting Strip (2 per Joint)

Material: No. 24 GA. (.0276) Galv. Steel Sheet



Assembly Description:

Armatures 22' - 6" Long are Fabricated Using the Galv. Steel Connecting Strips and Pop Rivets.

Fig. 8. Armature for mounting shielded thermocouples.

couple position will be known to within ± 0.5 cm.

The site survey requires the positioning of a target at the top centre of each instrument hole and the heater hole. Simple cylindrical plugs will be made for each hole with a target mark at the centre. The inclination of the instrument hole is measured by mounting the inclinometer on top of a pipe. The pipe is lowered into the borehole and readings are taken at two positions of the pipe, one at 180^0 rotation from the other. The average reading will be used to calculate the inclination of the borehole.

3. Interfaces with the Fluke Data Logger

The data collection system for this experiment consists of a Fluke data logger model 2400A, an assembly of transducers, signal conditioners and a recording device, acquired from several manufacturers (Fig. 22). In order to pass signals between the devices various mechanical and electronic interfaces were constructed:

- Irad stress meter data logger with Fluke data logger.
- Kennedy magnetic tape drive with Fluke data logger.
- Shielded thermocouples with Fluke data logger.
- USBM deformation meter's 10 channel strain bridge with Fluke data logger.
- Omega 10 channel back up scanner and strip chart with connector into Fluke scanner chassis.

The Irad data logger interface and the Kennedy tape drive interface were prepared by John Fluke Inc. These are electronic switching circuits (Fig. 9) which allow information to pass back and forth between the data logger and the external device only when the proper signals are presented to the data bus.

The shielded thermocouples are too large and inflexible to connect directly to a Fluke, ten channel connector block. It is therefore planned to interpose flexible leads which are in turn attached to connector blocks (Fig. 10). Leads from the USBM deformation meter conditioner are brought from the connector in the rear of the conditioner into a connector for the scanner chassis (Fig. 11).

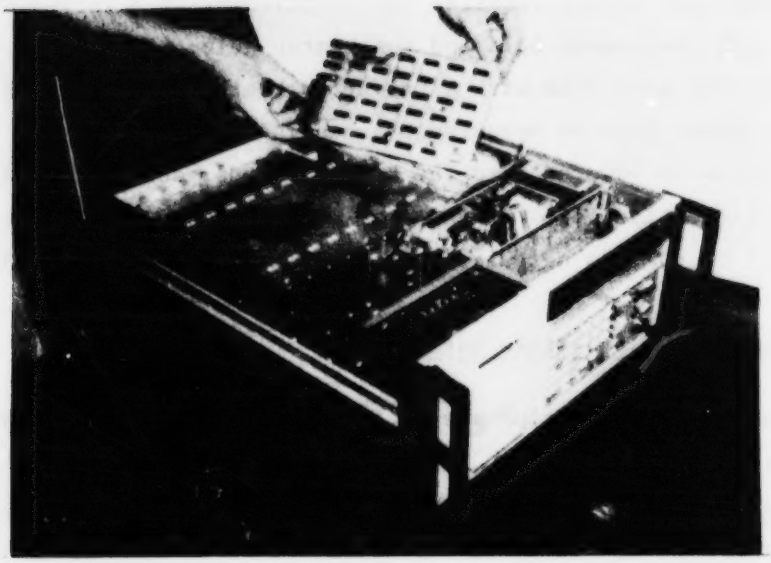


Fig. 9. Interface circuit between Fluke data logger and Irad data logger

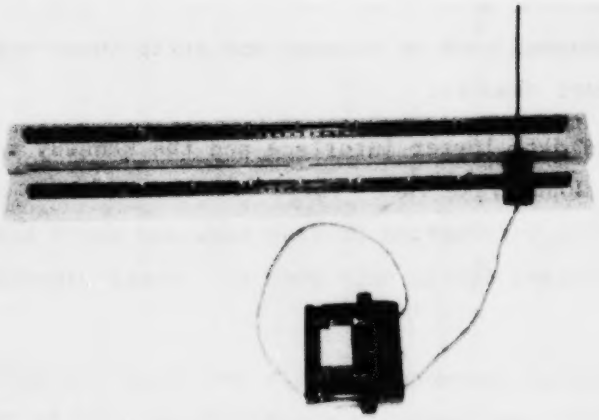


Fig. 10. Fastening block for shielded thermocouples showing flexible cable leading from the shielded thermocouple to the Fluke connector block.

4. Calibrations

Four types of transducers are to be used to measure the dependent experimental parameters:

- thermocouples
- thermistors
- vibrating wire stress meters
- borehole deformation meters using resistance strain gauges

One transducer, a digital inclinometer will be used to measure an independent variable, that is the horizontal displacement of the lower level of a borehole in relation to the top level.

The uncertainty in measurements made using these devices spring from three sources:

- individual transducer variability.
- deviation of the average response from standard calibration equation.
- noise introduced during the process of signal conditioning.

Transducer variability and noise generation can be minimized by careful use of the instrumentation but cannot otherwise be controlled by the user. Calibration errors however, are readily reduced by the calibration of each individual transducer. In the case of the shielded copper-constantan thermocouples used for measuring the field temperatures the error limits specified by the manufacturers are ± 1°C. When individual calibration was performed by NRC the quoted error limits were ± 0.2°C. Table 2 shows the error associated with the transducers before and after calibration.

The thermocouples purchased were of necessity derived from several different melts, since one melt provided too little material for all the required thermocouples. Thermoelectric properties are consistent within any one melt, so it is sufficient to calibrate one thermocouple from each different melt. The end result of calibrations were ten tables of measured thermoelectric voltages (Fig. 12) between 0°C and 300°C.

Considerable investigation of the behaviour of the Irad stress meters had to be undertaken before calibration could begin. Many characteristics of the cell response were not discussed in the manufacturer's literature

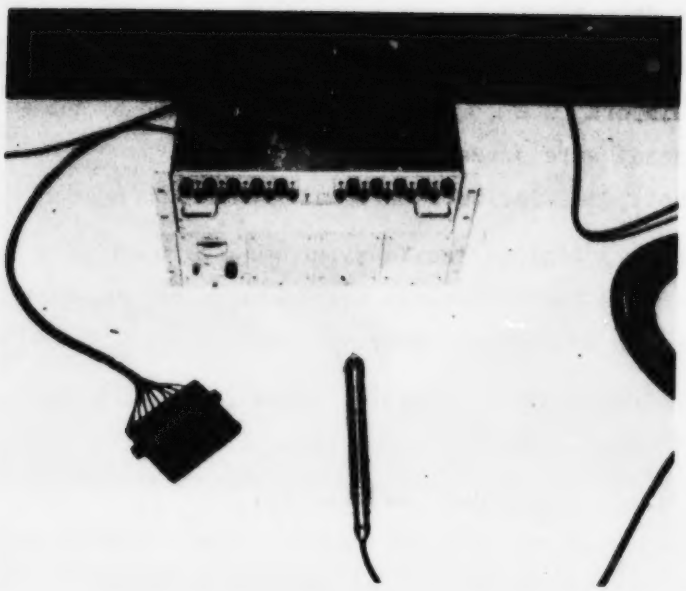


Fig. 11. U.S.B.M. conditioner and power supply (top) Fluke connector block (bottom left) U.S.B.M. deformation meter (bottom right)

11/05/78 THERMOCOUPLE CALIBRATION REPORT

COPPER-CONSTANTAN THERMOCOUPLE NUMBER 14 WAS CALIBRATED IN A STIRRED LIQUID BATH FROM 0 TO 300 C. THE ACCURACY OF CALIBRATION WAS 0.2 C. TABLES OF TEMPERATURE(IN DEGREES C) VS EMF(IN MICROVOLTS) ARE ENCLOSED. THE TEMPERATURES ARE IN TERMS OF THE INTERNATIONAL PRACTICAL TEMPERATURE SCALE OF 1968(IPTS-68).

T	EMF	T	EMF	T	EMF	T	EMF
0	0.0	50	2055.0	100	4309.9	150	6740.2
1	39.0	51	2098.2	101	4356.9	151	6790.4
2	78.0	52	2141.5	102	4403.9	152	6840.7
3	117.1	53	2184.9	103	4451.0	153	6891.1
4	156.4	54	2228.4	104	4498.1	154	6941.5
5	195.7	55	2271.9	105	4545.4	155	6992.1
6	235.1	56	2315.5	106	4592.7	156	7042.6
7	274.6	57	2359.3	107	4640.1	157	7093.2
8	314.2	58	2403.0	108	4687.5	158	7143.9
9	353.9	59	2446.9	109	4735.0	159	7194.7
10	393.7	60	2490.8	110	4782.6	160	7245.5

Fig. 12. Part of one thermocouple calibration table obtained from NRC

Table 2. Error Limits for Calibrated and Noncalibrated Transducers

Device	Error Limits before Calibration	Error Limits after Calibration	Error Resulting from using "Standard" Calibration
T type thermocouples	± 1°C	± 0.2°C	-
Vibrating wire stress meters	not specified	± 30%	- 50%
deformation meters	not specified	± 0.13μ m	+ 12%
inclinometer	± 0.006°	± 0.006°	Nil
thermistors	± 5°C	± 1.5°C	-

nor did they appear to have been studied by any other group. These characteristics were:

(1) thermal self loading due to the different thermal expansion rates of the gauge and the rock

(2) hysterisis effects which occur as the gauge goes through loading and unloading cycles

(3) settling of the gauge reading over a two day period after installation

(4) nonlinearity of the $(\text{frequency})^2$ vs load curve over a large range of loads

(5) a factor of two discrepancy in the quoted calibration sensitivity

(6) variation of the sensitivity with setting pressure

Overcoming some of these problems was not difficult, the gauges will be installed at least a week before the heater is turned on to make sure the readings have stabilized. The output from the cells will only be considered as long as it is monotonically increasing to avoid hysterisis problems. Finally the magnitude of the stress field will not be large enough to enter the range of nonlinear gauge response.

The test block taken from the experimental site to calibrate the Irad gauges is shown in Fig. 13. It is situated in a hydraulic press between two electrical resistance end heaters. The end heaters are insulated from

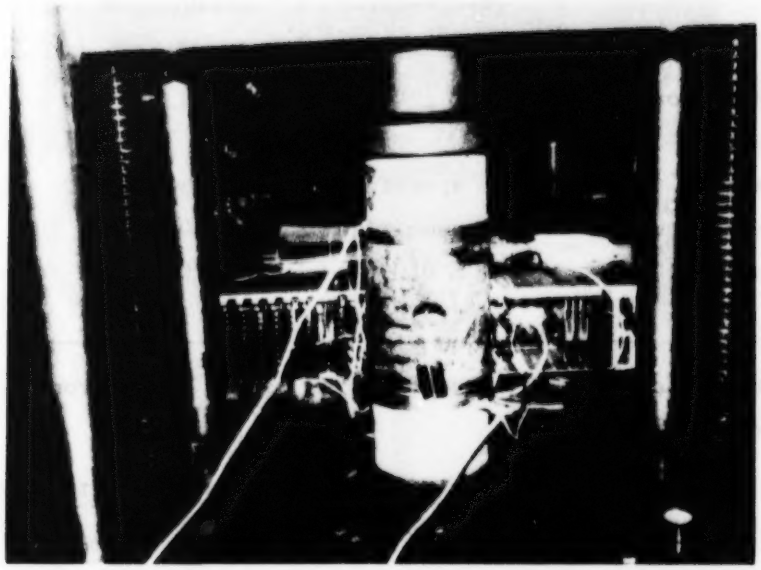


Fig. 13. Irad test block with end cap heaters and the Fluke scanner chassis in the background

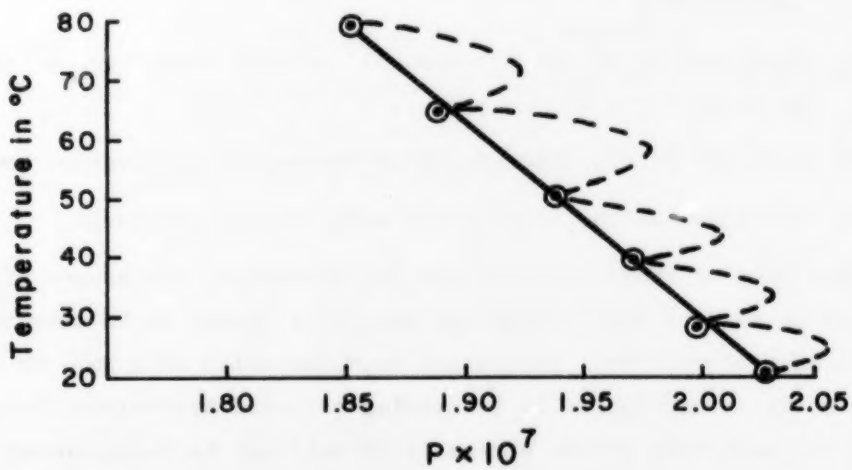


Fig. 14. Temperature calibration curve for an Irad gauge. Straight line is the result of thermal stresses

the press by columns of rock the same diameter as the sample but only 12 cm high. The stress sensitivity of each device was measured by varying the average verticle stress in the block between 25 MPa (3,500 psi) and 36 MPa (5,000 psi). This high initial stress in the rock simulates field conditions and avoids the nonlinearity in the rocks elastic modulus found at low stress levels. The gauges were installed using a hydraulic setting tool. The initial reading was adjusted to some convenient value in the range where the hydraulic setting pressure was between 5.9 MPa (850 psi) and 7.6 MPa (1,100 psi). The test was repeated on each cell five times. The average rate of change of $(\text{frequency})^2$ vs stress was calculated for each gauge as well as the estimate of the standard deviation for that value.

Calibration of the temperature sensitivity for an installed gauge was approached from two points of view. First the thermal expansion rate was measured for the rock and compared to that of the gauge (equation 1). Then the differential expansion of the gauge due to heating was equated to the differential expansion due to applied stress (equation 2).

$$\delta_T = (\alpha \text{ gauge} - \alpha \text{ rock})\ a\ \Delta T \qquad (1)$$

$$\delta_\sigma = 3\ a\ \Delta\sigma \qquad (2)$$

$\Delta\sigma$ = uniaxial stress change in direction of gauge orientation
ΔT = temperature change
a = radius of instrument hole
α gauge = coefficient of thermal expansion for the gauge
α rock = coefficient of thermal expansion for the rock
δ_σ = differential expansion of gauge due to stress
δ_T = differential expansion of rock due to temperature

If P is the linearized readout or hence the value of $(\text{frequency})^2$ for the vibrating wire then ΔP should be proportional to the differential expansion of the gauge no matter what the cause. If β is the proportionality constant between δ_T or $\delta\sigma$ and ΔP then:

$$\Delta P = \beta\ (\alpha \text{ gauge} - \alpha \text{ rock})\ a\ \Delta T = \beta\ 3a\ \Delta\sigma \qquad (3)$$

Rearranging 3 gives:

$$\frac{\Delta T}{\Delta P}\ (\alpha \text{ gauge} - \alpha \text{ rock}) = 3\ \frac{\Delta\sigma}{\Delta P} = 3\ \frac{\delta\sigma}{\delta\Delta P}$$

where $\delta\sigma/\delta\Delta P$ is a partial differential in this case.

or for a linear relation between ΔP and ΔT or $\Delta\sigma$

$$\frac{\delta\Delta P}{\delta T} = \frac{\Delta P}{\Delta T} = \left(\frac{\alpha \text{ gauge} - \alpha \text{ rock}}{3}\right) \frac{\delta\Delta P}{\delta\sigma} \qquad (4)$$

$\frac{\delta\Delta P}{\delta\sigma}$ is the stress calibration coefficient previously measured and α gauge and α rock are known. Hence the temperature calibration $(\frac{\delta\Delta P}{\delta T})$ for an installed gauge has been calculated in a semi theoretical fashion.

The second approach is to heat the sample block with the gauge installed. Heat was just applied from both ends of the block with the sides insulated. After a time the power to the heater was removed and the temperatures allowed to 'even out' to eliminate the imposition of the effects of thermal stresses on the effects of thermal expansion. The value ΔP was measured in this way for several values of rock temperature and the results plotted to obtain the value $\frac{\delta\Delta P}{\delta T}$ graphically (see Fig. 14).

Table 3. Irad Calibration Factors

stress	$\frac{\delta\Delta P}{\delta\sigma}$ empirical	1.3×10^{-11} sec^{-2}/psi
temperature	$\frac{\delta\Delta P}{\delta T}$ semi theroretical	26×10^{-11} sec^{-2}/°C
	empirical	29×10^{-11} sec^{-2}/°C

The Fluke data logger accepts thermocouple and thermistor transducers as direct input and transforms the input signals into temperatures in °C using internal tables. For a thermocouple the uncertainty in temperature is ± 1.5°C, for a thermistor it is ± 5°C.

Temperatures in the rock mass will be measured using the stainless steel shielded thermocouples. The temperature from each Irad gauge is to be measured by an internal thermistor. Although field temperatures at the Irad locations could be interpolated from thermocouple measurements it would be more reliable to calibrate the Irad thermistors to give an accurate measure of the gauge temperature.

This calibration was performed by attaching thermocouples to the

lrad cells and heating the cells gradually in a water bath, while at the same time recording the temperatures from both transducer types. What was achieved was a transformation table relating temperatures from the thermistor input channels to the more reliable temperatures from the thermocouple channels. When these tables are used to transform the thermistor data and the result is then corrected for the thermocouple calibration the uncertainty in the temperature value will be ± 1.5°C.

The USBM deformation meter consists of a cylinder with six internal cantilever beams, each butted agains a carbide steel button (Fig. 15). Three strain bridges are mounted internally; one bridge is attached to two opposing beams.

The sensitivity of the meter may be varied by adjusting the bridge power supply. A convenient sensitivity would be a 3.3 cm/volt (1.25 in/volt) with a six micron uncertainty in the final deformation.

The factor limiting the meter accuracy will be the data logger and power supply stability since the meter response is very linear. This was established using the calibration jig in Fig. 15.

The digital inclinometer is provided with its own conditioner and digital display unit. The internal calibration of the conditioner was checked by mounting the device on a rotating table in a vertical plane. Starting at -30 degrees to the vertical, in a vertical plane the axis of the meter was rotated to an orientation of +30 degrees to the vertical. The error found by the calibration was ±1 unit in the last digit. For near vertical angles this represents ± 0.006°. The only significant error encountered while using this device was the alignment error with the axis of the borehole whose inclination is being measured. In the case of the 3.8 cm boreholes this implies an uncertainty of ± 0.3 cm at a depth of 6.5 m and an uncertainty in the heater hole position of as much as ± 2.5 cm depending on the quality of the heater hole surface.

5. Computer Programming

Computer programming has been carried out to assist in two areas of the experiment. One area is in recovering the experimental data and transforming it into the most accurate values of stress, temperature or

position. These programs are the format conversion program FLKDTA, the calibration program DATADJ, and the survey programs SLANT1 and SLANT2. The other area is modeling in preparation for the experimental analysis. A series of programs were written to estimate thermal diffusivity from time dependent temperature data, another set of programs was developed that would calculate the stress and temperature boundary conditions around a region that was situated in an otherwise axisymmetric stress and temperature field.

When the experimental data first becomes available it will be examined to determine the optimum strategy to use in back calculating the thermo-mechanical rock properties at the experimental site.

5.1 SLANT1 and SLANT2

The Fortran program SLANT1 will be used to analyse the inclinometer data from the heater hole. The analysis will provide the centre line deviation of the heater hole from the vertical at any depth. This is done by projecting the inclinations of the heater hole (Fig. 17) calculated from the inclinometer readings taken at regular depths.

SLANT2 another Fortran program will be used to estimate the centre line coordinates of the heater hole at any depth. The coordinates will be in respect to a right hand cylindrical coordinate system whose origin is at the top centre of the heater hole, with a vertical Z axis and the $\Theta = 0^0$ axis on the north-south reference line.

5.2 FLKDTA and DATADJ

FLKDTA is a program which transforms the results of a "dump" of the magnetic tape from the Fluke data logger system into a readable format while at the same time it checks that obvious errors have not occurred in the data structure.

DATADJ is a Fortran program which will transform the output from FLKDTA into values of temperature stress and deformation using the calibration tables obtained in the laboratory. Modifications are still required to include the newly obtained calibration data.

Fig. 15. U.S.B.M. deformation meter (top left) Irad gauge (top right), deformation meter calibration jig (bottom left) platten for Irad gauge (bottom right)

Fig. 16. Heater segment (on bench) next to the concrete pipe in which it was tested.

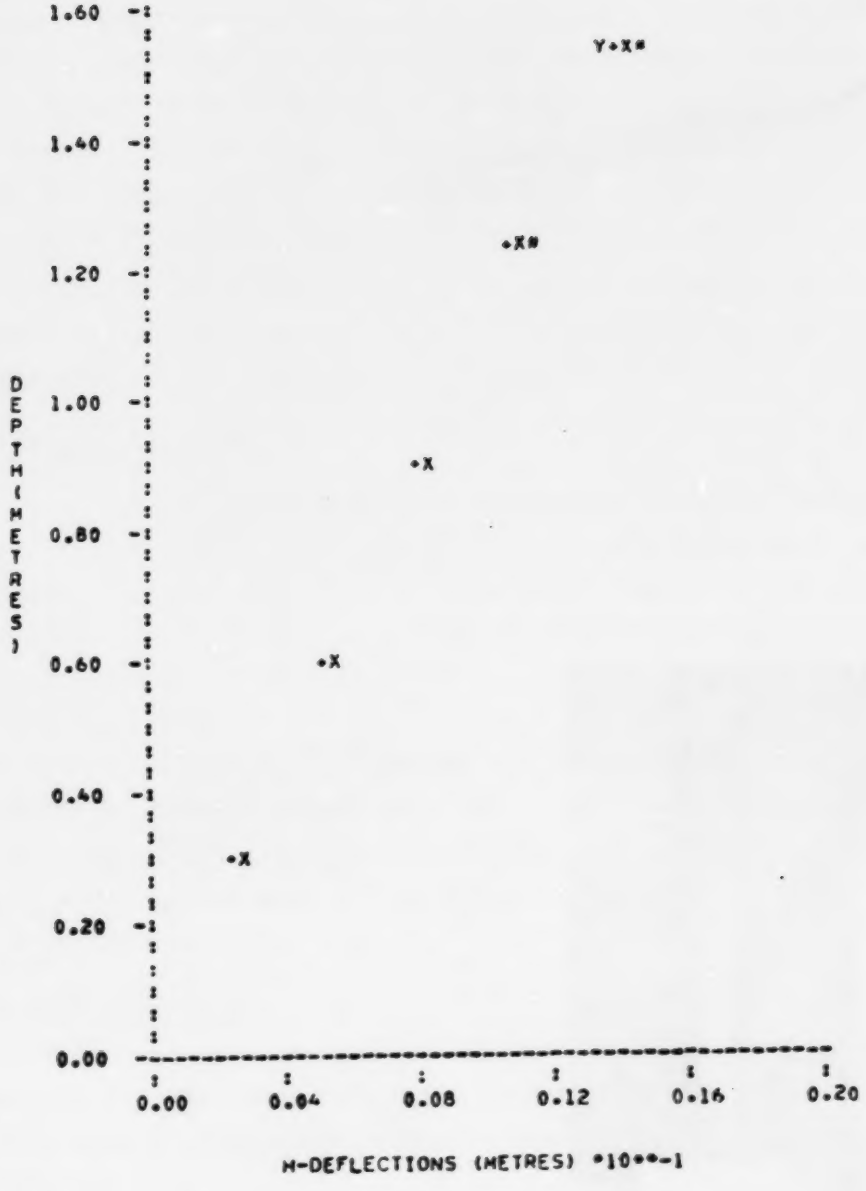


Fig. 17. A plot of the survey data analysed by SLANT 1

5.3 BNDTMP and BNOLD

These programs can and have been used to analyse the behaviour of the instrument holes in the neighborhood of an infinite cylindrical heater.

Without these programs it would be necessary to include the heater and the instrument hole in a two dimensional analysis. This would make the analysis of a region that was a reasonable distance from the heater too large to run inexpensively or too crude to give useful results. BNDLD and BNDTMP allow the user to calculate the stress and temperature boundary conditions around a region located in an otherwise axisymmetric stress and temperature field. These boundary conditions are obtained by interpolating discrete values of the radial stress and temperature data obtained by analysing a one dimensional axisymmetric finite element model of an infinite cylindrical heater.

5.4 Estimation of thermal diffusivity

A package of programs have been prepared to implement a nonlinear least squares procedure to estimate the thermal diffusivity of the material at the in situ site. The procedure requires a knowledge of a number of field temperatures as a function of time since the application of power to the heater. It also assumes a knowledge of a time-dependent temperature boundary condition on the heater hole wall.

This package was used to perform a study to estimate the effect of a systematic error in the temperature boundary conditions. This error could result from an inaccuracy in the measurement of the wall temperature or from an unusually low conductivity near the surface of the borehole wall because of the damage done in drilling. The diffusivity was calculated for one set of field temperatures 5% and 10% higher than the original temperatures. The 5% increase in boundary temperatures resulted in a 15% decrease in the calculated diffusivity. A 10% increase in boundary temperature gives a 28% decrease in the estimated diffusivity.

6. Equipment Testing

The in situ heater when assembled is a cylinder 6.5 m long and 30 cm in diameter, or 0.5 cm to 1.5 cm smaller in diameter than the heater hole. One segment, 164 cm in length was tested by operating it for eighteen

hours inside a vertical 190 cm length of concrete pipe. The pipe had an inside diameter similar to that of the expected diameter of the heater hole, about 31 cm (Fig. 16). The inside of the heater and the top of the pipe were insulated using fibreglass batting. Thermocouples were attached to the heater and to both the inside and outside surfaces of the concrete pipe. Power was applied to the segment and the temperature distributions along each surface were observed. Figs. 18 and 19 show the test temperatures after ten hours of heater operation at 860 watts. The pipe heated evenly around its circumference but there was a trend for the temperatures to be reduced towards the ends of the heater especially towards the bottom. The reduced temperatures near the bottom are thought to be a result of air convection. A similar effect is to be expected in the full size heater but it is not known how the additional heater length will affect the severity of the condition.

All heater segments were tested to insure that the heating elements were connected and operating properly. Several elements experienced ground faults and had to be replaced.

In order to evaluate the accuracy of the temperatures obtained on the surface of the heater hole or on the inside surface of the concrete pipe, it was necessary to do a comparative study of the metal disc system of attaching thermocouples to rock surfaces. In a separate test the temperatures measured using the metal disc system were compared with those measured by very fine thermocouples imbedded just below a concrete surface. The surface was heated using heat lamps and the incident radiation was diffused using a 1 cm thick copper plate (Fig. 20). The mean difference between the two techniques is 1.5°C. This is well below the 95% confidence level for the assumption that the two means are actually different. The results of the test indicate that the metal disc technique will provide a good relative measure of the rock surface temperature (± 2°C) for a heater where a constant input power strategy is being used. However, it is difficult to evaluate its effectiveness in measuring true surface temperature and it is even uncertain if the true surface temperature can be used to characterize the heat transfer into a medium since discontinuities in thermal properties could occur close to a surface. Consequently it is expected that the surface temperatures will be used mainly to estimate the heat flux distribution from the heater.

The operation of the data logging system for the experiment

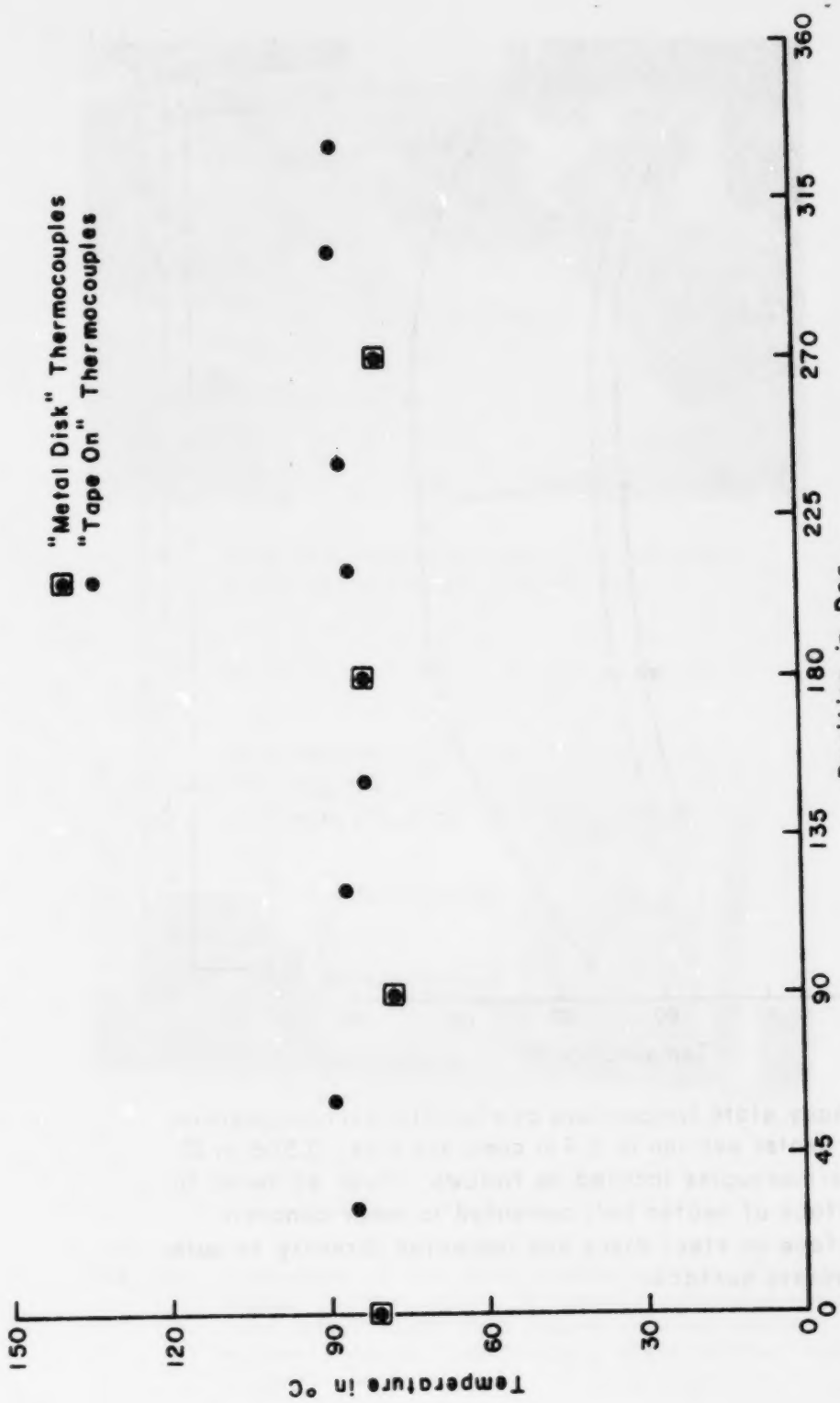


Fig. 18. Temperatures around the inside of the concrete test pipe after 10 hours of heater operation.

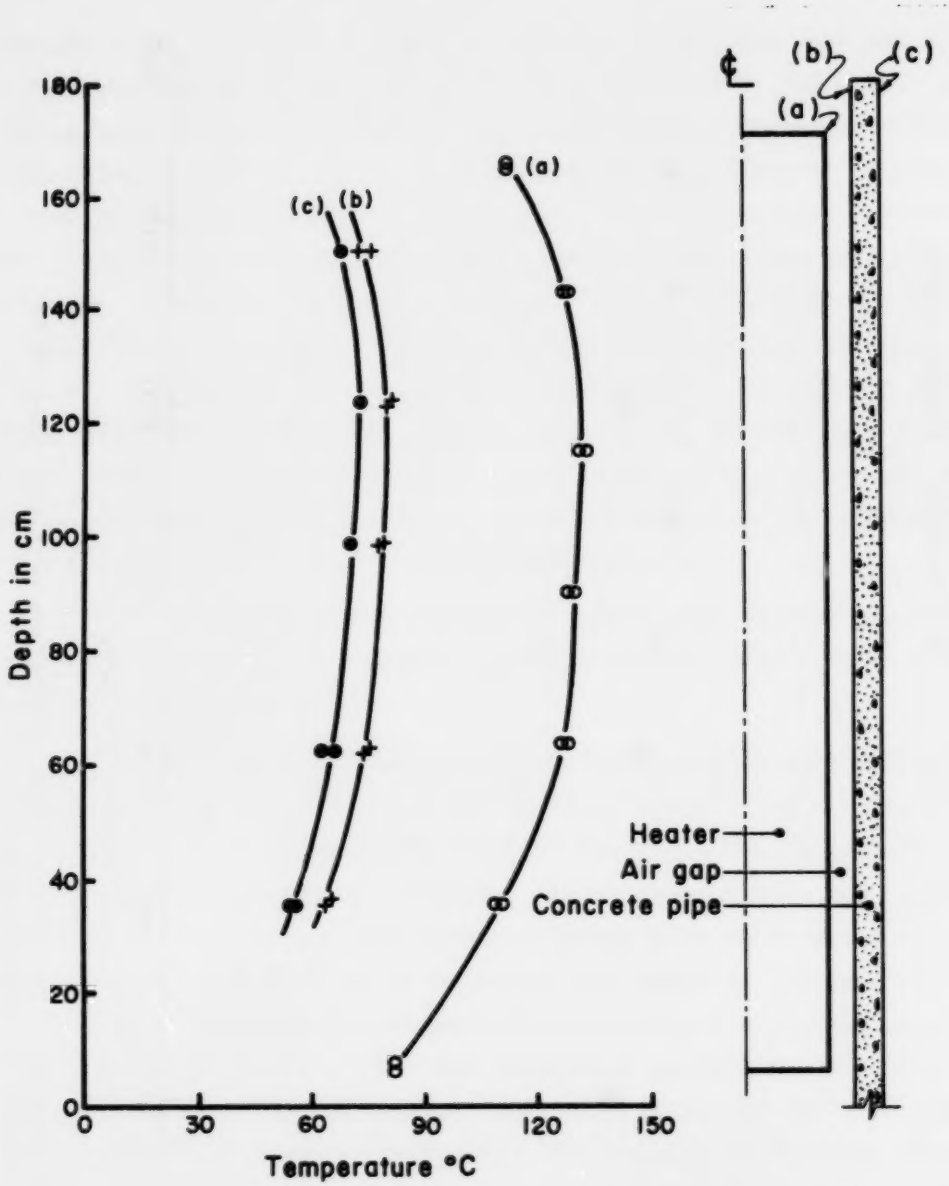


Fig. 19. Steady state temperature as a function vertical position for heater section in 2.4 m concrete pipe, 0.305 m Ø. Thermocouples located as follows: silver soldered to surface of heater (a), cemented to inner concrete surface on steel discs and cemented directly to outer concrete surface.

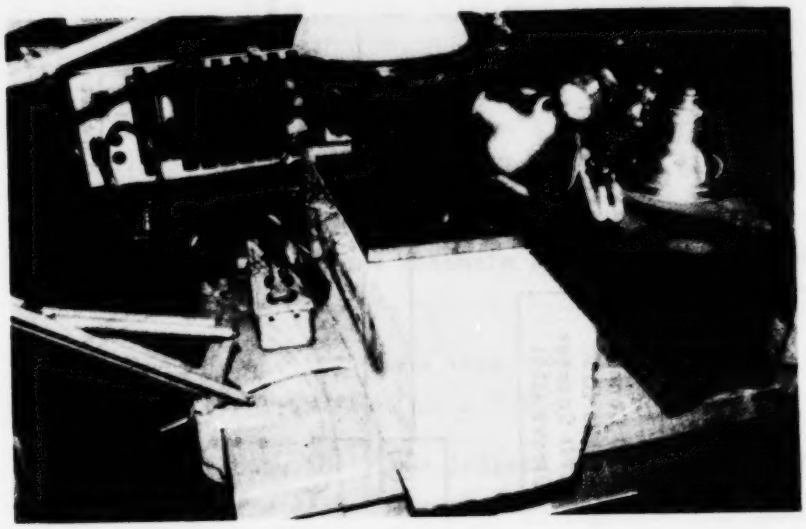


Fig. 20. Comparison test for metal disc technique of measuring surface temperatures.

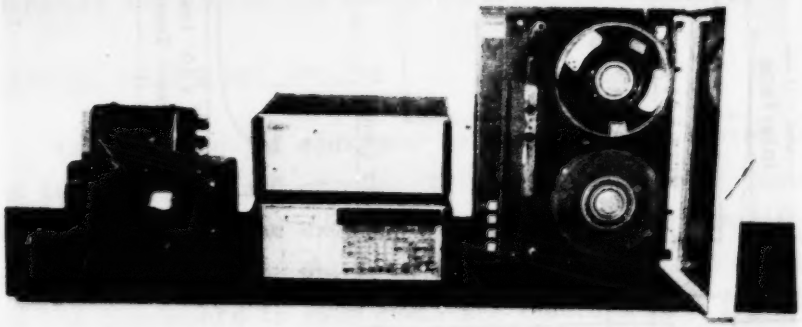


Fig. 21. Components of the data logging system: Irad data logger (bottom left); 10 channel switching module (top left); Fluke data logger (bottom centre); scanner chassis (top centre); Kennedy tape recorder. (right)

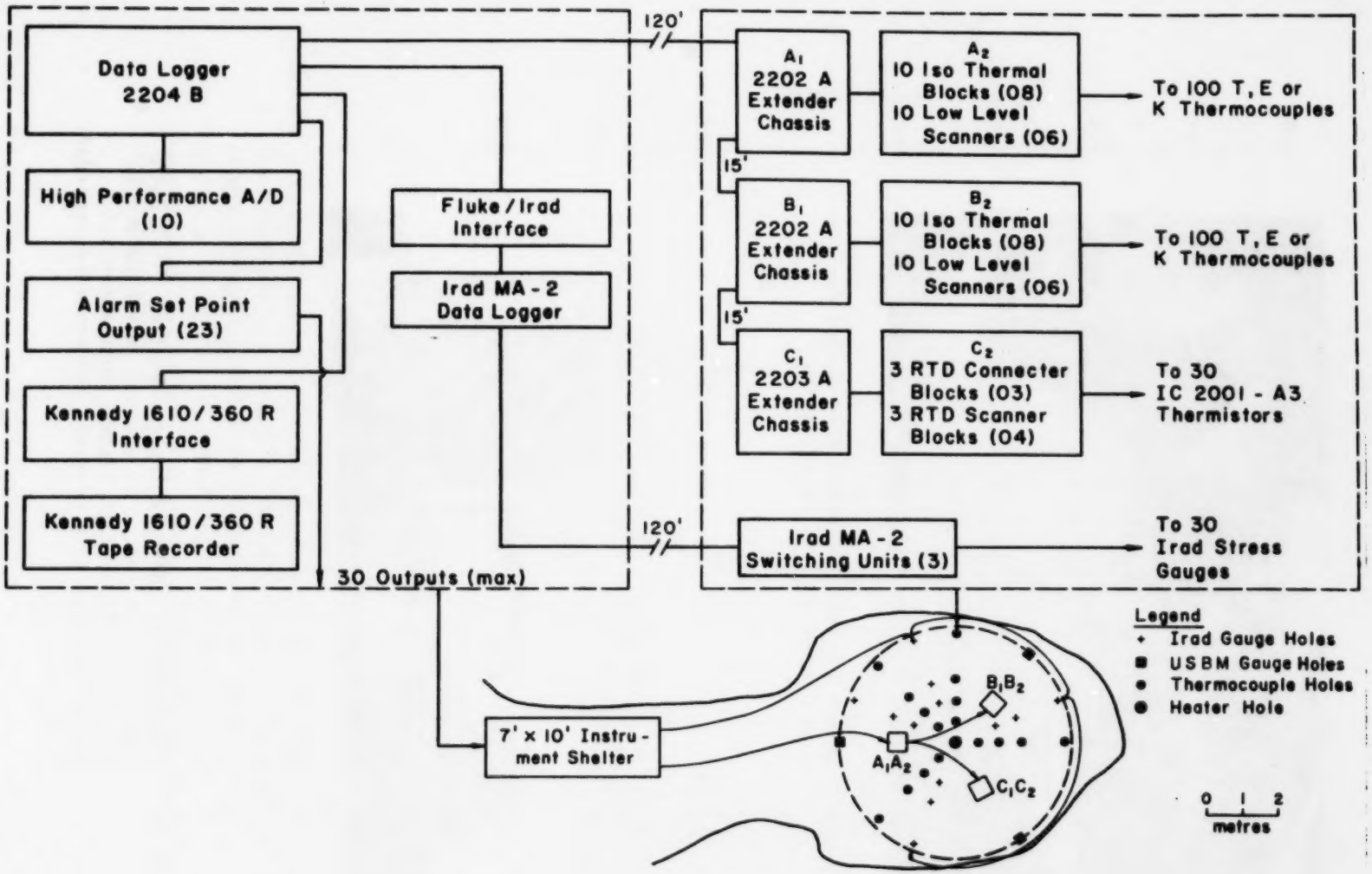


Fig. 22. Layout of experimental site and block diagram of data logging system.

(Figs. 21 & 22) were tested for the following functions:

- signal from each input channel, displayed on the proper output channel
- zero voltage input results in zero output
- temperatures measured using thermocouples agree within the limits of the specifications between channels and with other measurement techniques
- data scanned by the Irad data logger is transferred successfully and and accurately to the Fluke data logger
- the data printed on the Fluke loggers thermal printer agrees with data recovered from the magnetic tape for better than 99.5% of all characters
- the alarm triggering closes the proper relays

The data logger required servicing by the manufacturer before the recorded values of voltage and temperature were within the specified limits of accuracy. The Kennedy tape drive also required service before an acceptable data transfer rate was achieved. At the present time the system is operating satisfactorily and within the manufacturers specifications.

7. Equipment Logging and Crating

As each piece of equipment is completed and tested it is labelled, recorded in a log book and crated. (Fig. 23) The label is intended to uniquely identify a part and in the case of the transducers it identifies the instrument hole and the depth at which it is to be installed. As the packing procedes the components in each crate are recorded in a log book along with a record of the label on each component. The final check list for shipping will require only a list of the crate numbers. Once the installation begins each component can be located by referring to the log book. This should result in a quick, accurate installation of the instrumentation.

8. Future Plans

At this time there is a small amount of preparation to be completed before equipment is ready for shipment to Sudbury. The remaining tasks are:

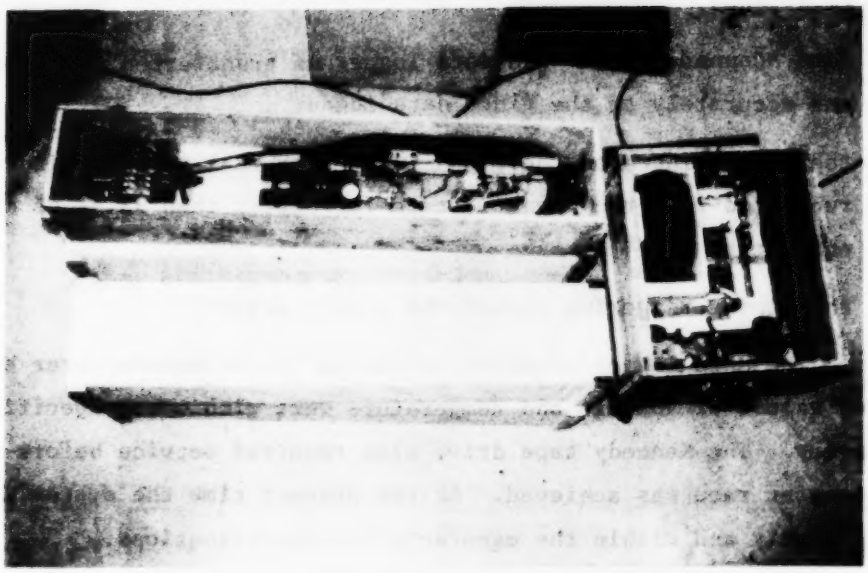


Fig. 23. Crated equipment ready for transport to Sudbury.

- preparation of simple survey accessories;
- test samples of Irad calibration block for values of elastic modulus;
- practice of the installation of three Irad gauges in one hole;
- modification of the data processing programs to include the new calibrations;
- completion of the wiring of the Omega strip chart recorder and scanner to a connector board to mate with Fluke connector blocks;
- completion of packing and logging.

The time table for equipment installation and the experiment itself has been delayed by the workers strike at Inco Metals Ltd. This has only recently been settled (on June 5, 1979). Appendix B is the time table of events leading up to the experiment. At least two weeks will be required to restart the mine. Contracts for the site preparation can then be renewed and Inco will begin to provide services to the test area so that the drilling can begin. After ten weeks from the mine reopening the site should be ready for instrumentation. Five more weeks should be sufficient to finish the installation and an additional four weeks will be required to obtain the data from the first experiment, for a total of twenty one weeks from the reopening of the mine.

9. Conclusion

The in situ heater experiment has suffered from a delay of almost one year because of the shutdown of the mine in which the experimental site is located. The extra time was used to improve the design of the heater and perform extensive calibrations on the experimental transducers, and include the USBM deformation meters as one of the transducer types. Although this has been an unfortunate but unavoidable delay it has provided the time to ensure that the installation and execution of the test will go smoothly and that the significance and the reliability of the transducer outputs will be well understood.

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APPENDIX A

Tasks Carried out in Preparation for In situ Test

Persons Responsible under the Direction of Mr. G. Larocque	Task
F. Kapeller with the assistance of G. Brooks	Heater construction Assembly of heater power supply and controller Design and construction of down hole carriage with - thermocouple mounting tool - down hole camera mount - inclinometer mount - borehole washer Attaching of connectors to shielded thermocouples Construction of mounting block to attach the ends of the shielded thermocouples USBM deformation meters connected to the data logger through Fluke connector block Crating of the heaters and thermocouples
D. Dugmore	Prepared working drawing for the heater and down hole carriage Prepared drawings for various reports and slide presentations
A. Annor	Assembled and checked survey instruments Logging of equipment Prepared computer programs to analyse inclinometer output
P. Carr	Testing of heater segment Theoretical analysis of inclinometer data treatment

	Developed computer code to convert a dump of the experimental tape into a readable format Computer program to transform experimental data according to laboratory calibration Computer programs to assist in calculating time dependent temperature and these boundary conditions around a region in the neighbourhood of an otherwise axisymmetric stress and temperature field
N. Toews, with assistance of A. Wong.	Computer programs used to estimate thermal diffusivity from experimental data Analysed the effect of discontinuities in the heater Developed a 3-dimensional, nonlinear temperature analysis finite element program
F. Kapeller R. Tervo	Devised method for measuring the surface temperature on the heater hole wall
P. Carr, B. Muir A. Annor, F.Kapeller	Calibration of Irad gauges for stress and temperature effects
P. Carr, F. Kapeller A. Annor	Calibration - inclinometer - USBM deformation meter - Irad thermistors - thermal expansion rate of site rock Testing data logging system Testing surface temperature measuring system
D. Lawlor (NRC)	Thermocouple calibration
G. Larocque	Arrangement of contract for site preparation and grouting
R. Tervo P. Miles	Contact with companies holding service contracts Preliminary heater developments

APPENDIX B

In situ Experiment Time-table

Date of Completion	Event
June 25	Renewal of contracts for - air and water supply - power - drilling instrument holes - removal fo steel casing - grouting of thermocouples
July 18	Installation of air and waterlines Removal of casing by diamond drilling
Aug 1	Drilling of heater hole Inco Ltd. surveys site
Aug 8	Rough check of Inco survey by EMR Drilling of instrument holes
Aug 15	Log core and select sections for testing Inco Ltd. surveys completed site EMR surveys completed site
Sept 3	Inco Ltd. installs gate on test site and electric power Down hole survey and photographic logging of heater hole Equipment moved from Ottawa
Sept 10	Set up instrument shack Install pump in heater hole Install wall thermocouples in heater hole Install thermocouples in instrument holes Test thermocouple operation with data logger
Sept 21	Grout thermcouple instrument holes

Oct 1	Install USBM meters Install heater
Oct 8	Pre-experimental test of system
Nov 5	Apply power to the heater for thirty days while recording data